(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
28 February 2002 (28.02.2002)

PCT

(10) International Publication Number
WO 02/17516 A2

(51) International Patent Classification[7]: H04B 10/10

(21) International Application Number: PCT/US01/25836

(22) International Filing Date: 17 August 2001 (17.08.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
09/642,164 18 August 2000 (18.08.2000) US

(71) Applicant *(for all designated States except US)*: LASER-MAX, INC. [US/US]; Building B, 3495 Winton Place, Rochester, NY 14623 (US).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: HOUDE-WALTER, William, R. [US/US]; 6902 East River Road, Rush, NY 14543 (US).

(74) Agents: SHAW, Brian, B. et al.; Harter, Secrest & Emery LLP, 1600 Bausch & Lomb Place, Rochester, NY 14604 (US).

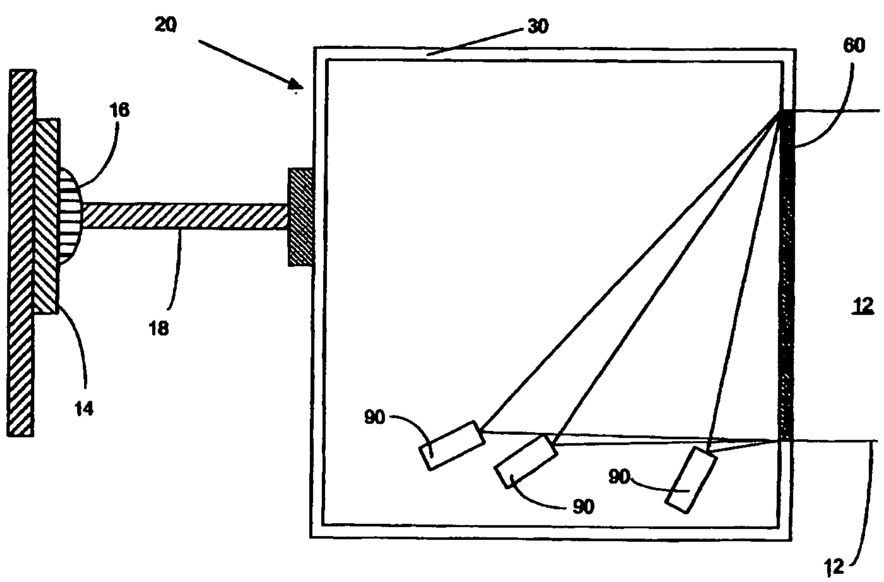
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii)) for the following designations AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG,*

[Continued on next page]

(54) Title: HOLOGRAPHIC OPTICAL TRANSCEIVER EMPLOYING DIFFRACTIVE OPTIC FOR ATMOSPHERIC FREE SPACE TELECOMMUNICATION



(57) Abstract: A diffractive optic multiplexer/demultiplexer for telecommunications is disclosed. The diffractive optic provides wavelength multiplexing/demultiplexing. The diffractive optic is located off-axis to at least one source of diverging coherent electromagnetic energy, wherein the diffractive optic is configured to collimate the diverging coherent electromagnetic energy along a communication axis. The diffractive optic can be bi-directional, thereby providing multiplexing for the diverging beams intersecting the diffractive optic an demultiplexing for intersecting multiplexed collimated communication beams.

WO 02/17516 A2

MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG)

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii)) for the following designations AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG)*

— *of inventorship (Rule 4.17(iv)) for US only*

Published:

— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

HOLOGRAPHIC OPTICAL TRANSCEIVER EMPLOYING DIFFRACTIVE OPTIC FOR ATMOSPHERIC FREE SPACE TELECOMMUNICATION

Field of the Invention

The present invention relates to free space optical telecommunication, and more particularly, to a self-multiplexing/demultiplexing large aperture optical device for producing, transmitting and receiving a collimated coherent communication beam.

Background of the Invention

While the capacity of data transmission over fiber optic and traditional conductive cable networks has greatly increased, these networks rely on coaxial cables or fiber optics extending between all nodes on the network. Cable networks must be trenched deep into the ground, buried under the sea or hung from poles and shielded from destruction or interference. Installation of such networks is time consuming and, therefore, expensive. Further, the maintenance of such networks is a critical and a costly component of an operating system.

Wireless communications in the form of radio frequency transmission are often employed in place of, or conjunction with the cabled networks. However, radio frequency communication is limited by available frequencies as well as the security of the transmitted information.

Alternatively, telescopes have been employed to collimate light sources and direct a signal to a predetermined location. However, to provide a relatively large aperture, the telescope optics dictates large optical surfaces. These large optical surfaces are difficult to manufacture and are therefore expensive. Alignment of such telescope systems requires extensive and complicated control equipment.

Free space, point-to-point microwave systems are used extensively in the communications field. A network of point-to-point microwave systems can carry messages across the country as part of the public switched telephone network. Despite strong competition from fiber optic based communications systems, microwave free space systems are often justified for shorter routes, when right-of-way for a cable system is not available, or when the high communications capacity of a fiber optic system is not needed.

Laser communication systems in particular have become increasingly popular to provide a free space communications link between two locations. Laser systems do not require extensive frequency coordination as do microwave systems in common frequency bands.

Laser systems often are less expensive to install than conventional cable or fiber optic cable communications systems because physical installation of a cable is unnecessary.

For example, a laser communication system may have application between two corporate locations in a campus environment. Each laser communication terminal may be positioned on a building rooftop or even positioned adjacent a window and aligned to operate between buildings. A communication link within a building may also be provided by a free space laser communication system. Modern office automation also typically generates large amounts of data that must often be communicated between different corporate locations. Accordingly, the demand for laser communication links is increasing.

Broadband point-to-point communications now often employ lasers in a point-to-point system that establishes a single continuous, high-speed, bi-directional, multi-channel, atmospheric connection. Laser based wireless systems have been developed for establishing point-to-point, bi-directional and high speed telecommunications through the atmosphere. The range for such systems is typically 0.5 to 1.2 miles, with some having a range of 4 miles or more. The longest atmospheric communications path achieved with a point-to-point system exceeded 100 miles. These single path systems require a laser and transceiver optics at each end of the connection. The connections are capable of maintaining high speed bi-directional communications in some of the most severe inclement weather conditions. The cost of such systems are typically in the $10,000 to $20,000 dollar range however, making them unsuitable for most home and business use.

Free space laser communication systems are considered stationary laser sources for regulatory purposes, and as such, must comply with regulatory limits established to protect the eyes of an accidental or unintended observer. An accidental observer may receive permanent damage from a high power laser beam without experiencing any pain which might forewarn the observer of the harmful exposure. In addition, the wavelengths used by laser systems are often invisible. Standards have been put in place that establish safe limits for the power that may be transmitted by a stationary laser source, such as a laser communication terminal. This maximum permissible power limits the signal-to-noise ratio, the bit rate, and/or the separation distance of the communication system.

Accordingly, there is a great need for a free space laser communication system and method that complies with safety limits, yet has improved performance over existing systems. A need also exists for point-to-point transmission systems which employ relatively inexpensive technology for transmitting and receiving data. The need further exists for a system that can accommodate thermal and mechanical variances without requiring substantial intervention or corrective components.

Summary of the Invention

The present invention includes a holographic optical transceiver for providing a broadband, point-to-point coherent communication beam in a continuous, high-speed, bi-

directional, multi-channel, atmospheric connection. In addition, the present invention allows for an optical signal to optical signal pass through, as well as an optical signal to electrical signal and an electrical signal to optical signal pass through. That is, an optical signal may pass through the invention or an electrical signal may be input and an optical signal output. Similarly, an optical signal may be received and a corresponding electrical signal generated by the present invention.

The present invention provides a free-space optical telecommunication device employing diffractive optics. In a preferred configuration, the diffractive optic is a hologram. The present invention provides for the atmospheric transmission of a collimated coherent energy communication beam, thereby obviating the need for a cabled network such as a fiber optics. Generally, the present optical communication apparatus includes a diffractive optic located off-axis to a plurality of diverging coherent beams, the diffractive optic configured to form a collimated communication beam. The diverging coherent beams may be produced by corresponding sources such as generators or the output of a fiber optic. Depending upon the number of transmitted beams, the communication beam may be multiplexed.

The present invention further provides a method of optic communication including passing a diverging coherent beam through an off-axis collimating diffractive optic such as a hologram. In a further configuration, a plurality of diverging coherent beams pass through the collimating diffractive optic to form a multiplexed collimated communication beam.

Additional configurations of the present invention provide a diffractive holographic collimating optic which is bi-directional and selected to demultiplex a collimated multiplexed coherent communication beam passing through the optic to form a plurality of virtual discrete point sources.

Brief Description of the Drawings

Figure 1 is a schematic representation of the communication device in an operating environment.

Figure 2 is a schematic representation of a configuration of the communication device.

Figure 3 is a schematic representation of an alternative configuration of the communication device.

Figure 4 is a schematic representation of a further configuration of the communication device.

Figure 5 is an enlarged view of a coherent transceiver sub-assembly and control mechanism.

Figure 6 is a schematic representation of another configuration of the communication device.

Figure 7 is a schematic representation of an additional configuration of the communication device.

Detailed Description of the Preferred Embodiments

The holographic optical transceiver 10 of present invention provides a system and method for bi-directional free space optical communication. In particular, the present invention allows for the creation, transmission and reception of a collimated communication beam 12 across free space, wherein the communication beam may be multiplexed and demultiplexed.

As used herein the term "free space" defines distances on the order of meters to kilometers, without the use of fiber optics. In contrast, current fiber optic devices may employ an optical signal spanning a gap on the order of a few tenths of millimeters.

The communication beam 12 includes, but is not limited to broadcast, digital data, interactive television, video telephony, video conferencing, video messaging, video on demand, high definition television (HDTV), high-speed data and voice. The communication beam 12 is a collimated beam of electromagnetic energy that propagates through free space. In certain configurations of the present invention, the communication beam 12 may also be multiplexed. Thus, the communication beam 12 includes a collimated multiplexed electromagnetic energy beam. The communication beam 12 may include a plurality of different wavelengths, wherein data is modulated on each wavelength of the light beams, thereby advantageously increasing the bandwidth. While the present system provides for extremely high speed transfer rates, it is contemplated the system can be employed at data rates commensurate with an associated service.

Referring to Figure 1, the present optical system contemplates a transmitting station and a receiving station. It is contemplated each station may be limited to a transmitting configuration or a receiving configuration respectively. However, for purposes of the present description, the stations are described as optical transceivers 20, in that each station can transmit as well as receive a communication beam. In addition, each station can be configured for multiplexing and demultiplexing (mux/demux). Although not intended to be limited to such configuration, the stations of the present system are set forth in terms of optical transceivers configured for transmission and reception, as well as mux/demux.

The optical transceivers 20 are located along a line of sight path. The line of sight may include a straight linear path. It is understood, the line of sight may include redirection by one or a plurality of reflective surfaces, such as mirrors. For clarity of description, the line of sight is depicted as a linear path shown in Figure 1.

The anticipated size of the optical transceivers 20 allows for installation on the tops of buildings, roofs as well as the sides of the buildings, without requiring extensive weight

bearing supports. Preferably, the optical transceiver 20 is sufficiently connected to a building or structure to substantially preclude movement of the transceiver relative to the building. That is, environmental factors such as wind, temperature and snow loading do not alter the position of the transceiver 20 relative to the building.

Referring to Figures 2 and 3, typical mounting of the transceiver 20 includes a mounting plate 14, a coupling 16 and a support arm 18. The mounting plate 14 is affixed to the building or structure, wherein the coupling 16 is attached to the mounting plate. The support arm 18 extends between the transceiver 20 and the coupling 16. The coupling 16 is constructed to be selectively tightened to retain the support arm 18 and hence transceiver 20 in a predetermined orientation relative to the building. The support arm 18, the coupling 16 and the mounting plate 14 may include a through passage for passing a power supply line as well as any communication lines, such as fiber optics to the transceiver 20.

As shown in Figures 2-4, 6 and 7, the optical transceiver 20 includes a housing 30, a diffractive optic 60, a transmitter 70 and a receiver 80.

The housing 30 may have any of a variety of configurations and is typically dictated by the configuration of the diffractive optic 60. Preferably the housing 30 is configured to form a rigid frame to which the remaining components are connected. The frame may be a variety of materials including metals, plastics, laminates and composites. The construction of the housing 30 may also be partially determined by environmental considerations including thermal expansion.

The diffractive optic 60 is located to intersect at least one diverging beam 8 and transmits a refracted communication beam 6, wherein one of the diverging beam and the refracted communication beam are off axis to a plane of the diffractive optic. In a preferred configuration, the diffractive optic 60 is a holographic interference pattern in a substrate. The substrate can be a surface, a volume or a mirrorized relief. In a preferred configuration, the diffractive optic 60 is constructed to perform a variety of functions including collimation, beam shaping and multiplexing of the diverging beam 8. The multiplexing includes spatial and wavelength multiplexing. However it is understood, the diffractive optic 60 can be employed to perform just the collimation function, wherein the beam shaping is accomplished by additional optical surfaces. The diffractive optic 60 is selected to form a wavelength dependent virtual point source off axis to an entering collimated communication beam or collimate a diverging coherent beam passing off-axis through the diffractive optic to form a collimated communication beam. As seen in Figures 2, 3, 4, 6 and 7, the diffractive optic 60 is located off-axis to at least one of the transmitters 70 or receivers 80, and is selected such that the communication beam 12 passes through the diffractive optic.

Referring to Figure 4, the diffractive optic 60 may be constructed as a reflective (mirrorized) element. In this construction, the diffractive optic 60 includes the hologram and

a reflective surface 64. In such construction, the reflective surface 64 is located such that a diverging beam 8 enters the hologram from an off-axis orientation, reflects off the reflective surface and passes from a transmissive plane of the diffractive optic as a collimated beam 12.

The hologram (diffractive optic) can be constructed in a number of configurations for addressing the diverging beams 8 and the communication beam 12. As shown in Figures 2, 3 and 4, the diffractive optic 60 can be configured to receive the diverging beams 8 over substantially the entire area of the diffractive optic and to transmit the collimated communication beam 12 over substantially the entire area of the diffractive optic.

Alternatively, as shown in Figures 6 and 7, the diffractive optic 60 can include a portion 66 dedicated to transmitting (collimating) the communication beam(s) and a separate portion 68 dedicated to receiving (decollimating) the communication beam, thus providing a dedicated hologram. In the dedicated hologram configuration, one of the receiver 80 or the transmitter 70 can be located on axis with the respective communication beam 12. That is, the receiver(s) 80 can be located on axis, while the transmitter(s) 70 is located off-axis. The dedicated hologram can have any of a variety of configurations. In an exemplary configuration, the transmitting portion 66 may be centrally located in the hologram, with the receiving portions 68 spaced about the central transmitting portion. Another construction contemplates an array of receiving portions 68 and an array of transmitting portions 66. It is understood the arrays may be interspersed or separate. In further constructions, separate portions of the transmitting or receiving array can be dedicated to separate wavelengths, or channels.

The dedicated hologram construction can be configured to transmit and receive separate wavelengths to separate portions of the hologram. Thus, multiple wavelengths can be transmitted and received through an integral diffractive optic, without multiplexing or demultiplexing. In addition, with the dedicated hologram configuration, the need for beam splitters can be obviated as the hologram directs the relevant wavelength to the respective receiver 80, without having to accommodate for the transmitter 70 being aligned along the same axis.

The diffractive optic 60 may have any of a variety footprints. That is, the periphery may be square, rectangular, multi-faceted or curvilinear. As the periphery of the diffractive optic 60 corresponds to the area of the diffractive optic and the area of the diffractive optic allows for control of the energy density of the communication beam, it is anticipated that the periphery of the diffractive optic will be selected to maximize the available cross sectional area of the communication beam. As the cross sectional area of the communication beam 12 is maximized, the corresponding energy density of the communication beam is minimized.

Typical cross sectional areas of the diffractive optic 60 and hence communication beam 12, can range from approximately 4 square inches to approximately 2,400 square

inches or more. Preferably, the diffractive optic 60 is selected to be as large as possible, thereby minimizing the energy density of the resulting collimated beam. In contrast to prior systems employing telescopes, with the attendant mirrors and reflectors, the present system employs the diffractive optic 60, such as a hologram, to form a large aperture collimated communication beam. The creation of a large aperture communication beam 12 allows for higher energy transmission, while remaining within acceptable energy densities.

The transmitter 70 is an electromagnetic beam source. While the electromagnetic beam source may be any of a variety of electromagnetic energy forms such as visible or non-visible radiation, for purposes of the description the electromagnetic beam source is coherent and understood to be a laser. Typical lasers include LED or diode lasers. The lasers can produce a beam in the visible spectrum as well as near infrared or infrared. Preferably the wavelengths are in the near infrared range. In one configuration, the lasers are eye safe, class one lasers in accordance with FDA standards. It is understood alternative standards may apply or be followed, such as the American National Standards Institute (ANSI) or CDRH standards. However, it is understood the "beam" encompasses any of various types of light transmission, including lasers, a super-fluorescent light source, or other coherent and/or non-coherent light or optical transmission. It is also understood, the coherent electromagnetic beam source 70 maybe emissions from a fiber optic through which an optical signal has passed as shown in Figure 3. In such construction, an optical amplifier 22 may be located in the housing 30 to boost the signal strength of the diverging beam 8. A typical optical amplifier is an erbium doped fiber amplifier (EDFA) .

The use of a particular wavelength of laser light provides high bandwidth with only slight attenuation in the atmosphere. The light beam wavelengths generated by the atmospherically transmitting light sources described in the present invention are chosen to minimize the power loss through the atmosphere. The transmitter 70 is connected to a signal generator. The signal generator is known in the art and causes the transmitter to emit modulated beams.

The coherent light source of the transmitter may be any of a variety of lasers, and in particular, a laser diode has been found effective. Preferably, the laser diode produces a diverging beam extending from the source to the diffractive optic. However as shown in Figure 5, optical surfaces 72 can be employed to cause a collimated beam to diverge. Alternatively, in cooperation with the particular diffractive optic 60, the optical surfaces 72 can be selected to shape the diverging beam 8. Preferably, the diffractive optic 60 is sized and the coherent light source is spaced from the diffractive optic to optimize the area of the diffractive optic intersecting the respective diverging beam.

The receiver 80 is selected to receive an incoming decollinated communication beam 6 or portion of the communication beam 12. In one configuration, the receiver 80 is a photo-

detector dedicated to a particular wavelength. The receiver 80 may also be selected as an optical device for transferring the optical signal of the decollinated beam to a downstream optical system. It is also understood the receiver 80 can be selected to receive the decollimated beam 6 and generate a corresponding electrical signal.

The transmitter 70 and receiver 80 can be separate components as shown in Figures 6 and 7. However, the transmitter 70 and the receiver 80 can be combined into a laser transceiver subassembly 90 as seen in Figures 2, 4 and 5.

Referring to Figure 5, each laser transceiver subassembly 90 generally includes a coherent energy source (transmitter) 70, a photodetector (receiver) 80 and a beam splitter 86. The beam splitter 86 is optically intermediate the coherent energy source 70 and the diffractive optic 60. Similarly, the photodetector is located to dispose the beam splitter 86 optically intermediate the diffractive optic 60 and the photodetector.

As shown in Figure 3, a secondary diffractive optic 40 is employed with the diffractive optic 60. In this configuration, the secondary diffractive optic 40 emulates a point source for a given wavelength, wherein the signal from the emulated point source diverges to the diffractive optic 60 to be collimated into the communication beam 12.

The diffractive optic 60 and the transceiver subassemblies 90 are selected to uniquely locate each transceiver subassembly relative to the diffractive optic. As shown in Figure 2, the transceiver subassemblies 90 are spaced from each other and the diffractive optic 60.

Although three laser transceiver subassemblies 90 are shown, it is understood just a single transceiver subassembly may be employed. Similarly, a larger number of laser transceiver subassemblies 90 may be located in the housing and optically aligned with the diffractive optic 60.

Typically, each laser transceiver subassembly 90 is connected to a signal source such as an electronic signal (from an Ethernet) or an optical signal from a fiber optic.

A micro-positioning assembly 50 is connected to the housing and the laser transceiver subassemblies 90 to orient the laser transceiver subassemblies with respect to the diffractive optic 60. Preferably, the micro-positioning assembly 50 is remotely controllable. Further, the micro-positioning assembly 50 is controllable about two, and preferably three axis to manipulate the direction of the respective beam propagation with respect to the diffractive optic 60. The micro-positioning assembly 50 can include a yoke 52 and at least one motive device 54, such as a micro-server or motor. The yoke 52 may be constructed to engage each receiver 80, transmitter 70 or laser transceiver subassembly 90. Alternatively, each receiver 80, transmitter 70 or laser transceiver subassembly 90 may be individually connected to a corresponding yoke 52 which in turn is independently connected to a corresponding motor 54, or directly connected to a respective motor. In an alternative construction, the micro-

positioning assembly 50 includes piezoelectrics, screws bi-morphic flexures or similar structures.

Thus, in contrast to prior devices wherein the laser source and the hologram are locked together and moved as a single unit, the present system adjusts the laser transceivers independent of movement of the diffractive optic. Thus, the present system allows for dynamic adjustment of the diverging beams 8 relative to the diffractive optic 60 in real time.

It is further contemplated that a feedback system 56 is operably connected to the micro-positioning assembly 50 and the laser transceiver subassemblies 90. The feedback system generally monitors signal strength and controls the micro-positioning assembly 50 to maximize available signal strength.

Operation

In operation of the configuration of Figure 5, the laser of each transceiver subassemblies 90 is modulated in accordance with the signal from a corresponding signal generator or source. The modulated beam 8 passes from the laser through the beam splitter 86 to intersect the diffractive optic 60 at the predetermined, non-perpendicular angle. That is, as previously discussed, the diffractive optic 60 is located off-axis from the direction of propagation of the diverging beam 8. The modulated coherent beam 8 passes through the diffractive optic 60 and is redirected along a collimated communication beam axis. In the preferred construction, the diffractive optic 60 also multiplex the diverging beams as well as shape the beam.

At the receiving end, the collimated modulated (multiplexed and/or shaped) communication beam 12 passes through the diffractive optic 60, whereby individual wavelengths are diffracted to virtual point sources and particularly the beam splitter 86 of the respective transceiver subassembly 90. A portion of the signal is directed to the photodetector where the optical signal is converted to an electrical signal.

Referring to Figure 3, in a transmitting mode, an input signal passes along the fiber optic and through the diverging lens (if necessary) to pass to the secondary diffractive optic 40. The secondary diffractive optic 40 forms a plurality of virtual point sources which are directed to the off-axis diffractive optic 60 which culminates the signals into a communication beam 12.

In a receiving scenario, the (multiplexed and/or shaped) collimated communication beam 12 passes through the diffractive optic 60, wherein, depending on the number of wave lengths, a corresponding number of converging beams are formed. These beams intersect the secondary diffractive 40 optic and collectively converge to an input lens to the fiber optic.

Referring to the configuration of Figure 4, the reflective diffractive optic (hologram) is employed in the housing 30. The laser transceiver subassemblies 90 are disposed within

the housing 30 beyond the footprint of the collimated communication beam 12. In transmitting, the laser transceiver subassembly 90 generates (or transmits) a diverging coherent beam 8 which intersects the diffractive optic 60 in an off-axis orientation. The diverging beam 8 reflects off the reflective surface 64 of the hologram and is projected as a collimated communication beam 12 exiting the housing 30 along the communication beam axis.

In the receiving mode of the configuration of Figure 4, the collimated communication beam 12 passes through the housing 30 and through the diffractive optic 60 to be reflected from the reflective surface 64 and towards the respective laser transceiver subassemblies 90.

Referring to Figure 6, in the dedicated configuration of the diffractive optic 60, the transmitters 70 are located off-axis to a portion of the diffractive optic 60 and each respective diverging beam 8 intersects the diffractive optic to form the collimated communication beam 12 extending along the communication beam axis. In this dedicated diffractive optic, the incoming communication beam 12 intersects the diffractive optic 60 in a separate location than the transmitted communication beam. The incoming communication beam passes through the diffractive optic 60, wherein the respective wavelengths are directed to discrete point sources and corresponding photo detectors. Thus, the configuration of Figure 6 does not require a beam splitter 86.

Referring to Figure 7, a reflective dedicated diffractive optic 60 (hologram) is employed. In this configuration, the diverging coherent beam 8 emanates from a respective transmitter 70, passes through the diffractive optic 60, reflects through off the reflective surface 64 to form the collimated communication beam 12 extending along the communication beam axis. An incoming communication beam 12 intersects a separate portion of the diffractive optic 60, passes through to the reflective surface 64, wherein specific wavelengths are directed to corresponding point sources located off-axis and preferably outside the footprint of the incoming communication beam.

The present system thus provides a single optic which collimates, mux/demuxes and beam corrects, such as beam shapes. The system is particularly suitable for diode lasers. Specifically, diode lasers tend to exhibit astigmatism such that the resulting coherent beam has an elliptic cross section. The present diffractive optic 60 can be readily constructed to compress the ellipse to a circular cross section, thereby shaping the beam.

In addition, the diameter of the communication beam 12 leaving the hologram is many times the diameter of the beam 8 exiting the transmitter 70 or light source generator (or fiber optic). Thus, the energy of the signal is spread over a relatively large, cross-sectional area, which enhances eye-safety. Additionally, the relatively large diameter of the communication beam 12 traveling between the components of the network improves the reception characteristics of the communication beam at the optical receivers.

It is further contemplated the present invention can communicate with an alternative structure such as a conventional telescope system.

While the invention has been described in connection with a presently preferred embodiment, those skilled in the art will recognize that modifications and changes may be made therein without departing from the true spirit and scope of the invention, which accordingly is intended to be defined by the appended claims.

In the Claims

1. An optical communication apparatus for transmitting a communication beam in free space, the apparatus comprising:

(a) a plurality of modulated diverging coherent electromagnetic energy sources selected to produce a corresponding plurality of diverging beams; and

(b) a diffractive optic located off-axis to the plurality of diverging beams, the diffractive optic configured to refract the diverging beams into a collimated communication beam.

2 The optical communication apparatus of Claim 1, further comprising a positioning assembly connected to the sources to alter a direction of the corresponding diverging beams relative to the diffractive optic.

3. The optical communication apparatus of Claim 1, wherein the diffractive optic is a hologram.

4. The optical communication apparatus of Claim 3, wherein the hologram collimates, multiplexes and beam shapes the plurality of diverging beams.

5. An optical transceiver, comprising:

(a) a diverging coherent electromagnetic beam source emitting a diverging electromagnetic beam along an axis; and

(b) a diffractive optic optically intersecting the diverging coherent electromagnetic beam in an off-axis orientation, the diffractive optic selected to collimate the diverging beam along a communication axis.

6. The optical transceiver of Claim 5, wherein the diffractive optic is a hologram.

7. The optical transceiver of Claim 5, further comprising a second diverging coherent electromagnetic beam source emitting a second diverging electromagnetic beam along a second axis.

8. The optical transceiver of Claim 6, wherein the diffractive optic is selected to collimate, multiplex and beam shape the diverging coherent electromagnetic beam and the second diverging coherent electromagnetic beam.

9. The optical transceiver of Claim 5, wherein the diffractive optic is planer.

10. A method of optical communication, comprising:

(a) passing a diverging coherent beam through an off-axis collimating diffractive optic to form a collimated communication beam in free space.

11. The method of Claim 10, further comprising passing a plurality of diverging coherent beams though the diffractive optic to form the communication beam.

12. The method of Claim 10, wherein the diffractive optic is selected to multiplex the diverging coherent beam.

13. The method of Claim 10 wherein the diffractive optic is selected to shape the diverging coherent beam.

14. The method of Claim 10, further comprising employing a hologram as the diffractive optic.

15. A method of optical communication, comprising:

(a) passing a collimated multiplexed coherent energy communication beam through a diffractive optic to diffract the coherent energy to emulate a plurality of discrete point sources, at least one of the emulated point sources located off-axis to the communication beam.

16. The method of Claim 15, wherein each point source is substantially monochromatic.

17. The method of Claim 15, further comprising generating a plurality of virtual point sources upon passing the collimated multiplexed coherent energy communication beam through the diffractive optic.

18. A method of forming a communication beam, comprising:

(a) projecting a plurality of modulated coherent energy beams through an off-axis diffractive optic to form a collimated communication beam.

19. A method of forming a collimated free space modulated communication beam, comprising:

(a) passing a modulated light beam through an off-axis hologram selected to collimate the beam through free space.

20. An optical communication apparatus for transmitting a communication beam in free space, the apparatus comprising:

(a) a planar hologram;

(b) a diverging coherent beam source for emitting a diverging coherent beam along an emitting axis, the emitting axis non perpendicularly intersecting the hologram, the hologram selected to collimate the diverging coherent beam.

21. The optical communication apparatus of Claim 20, further comprising a secondary hologram optically intermediate the planar hologram and the diverging coherent beam source.

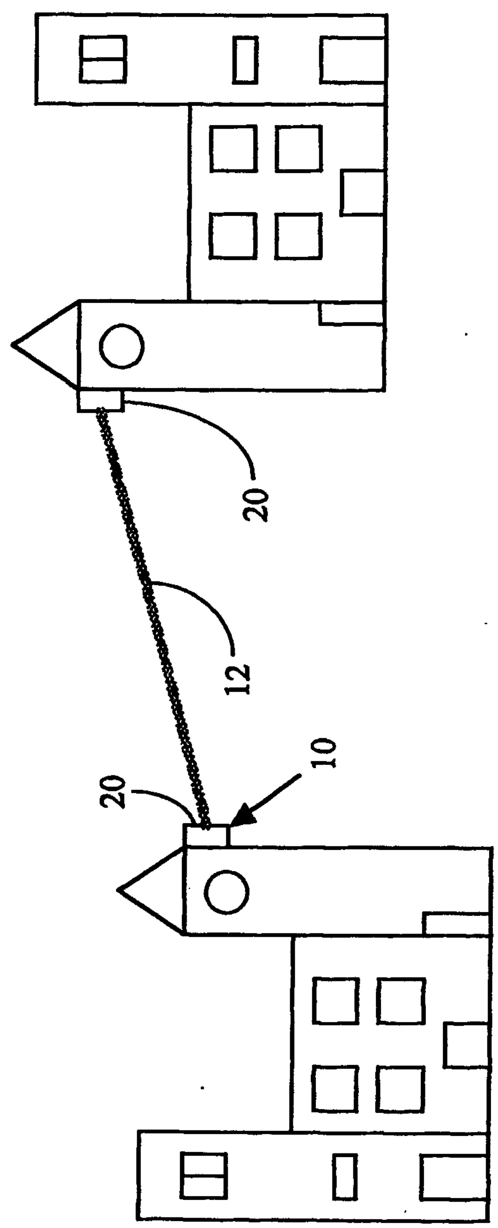


FIGURE 1

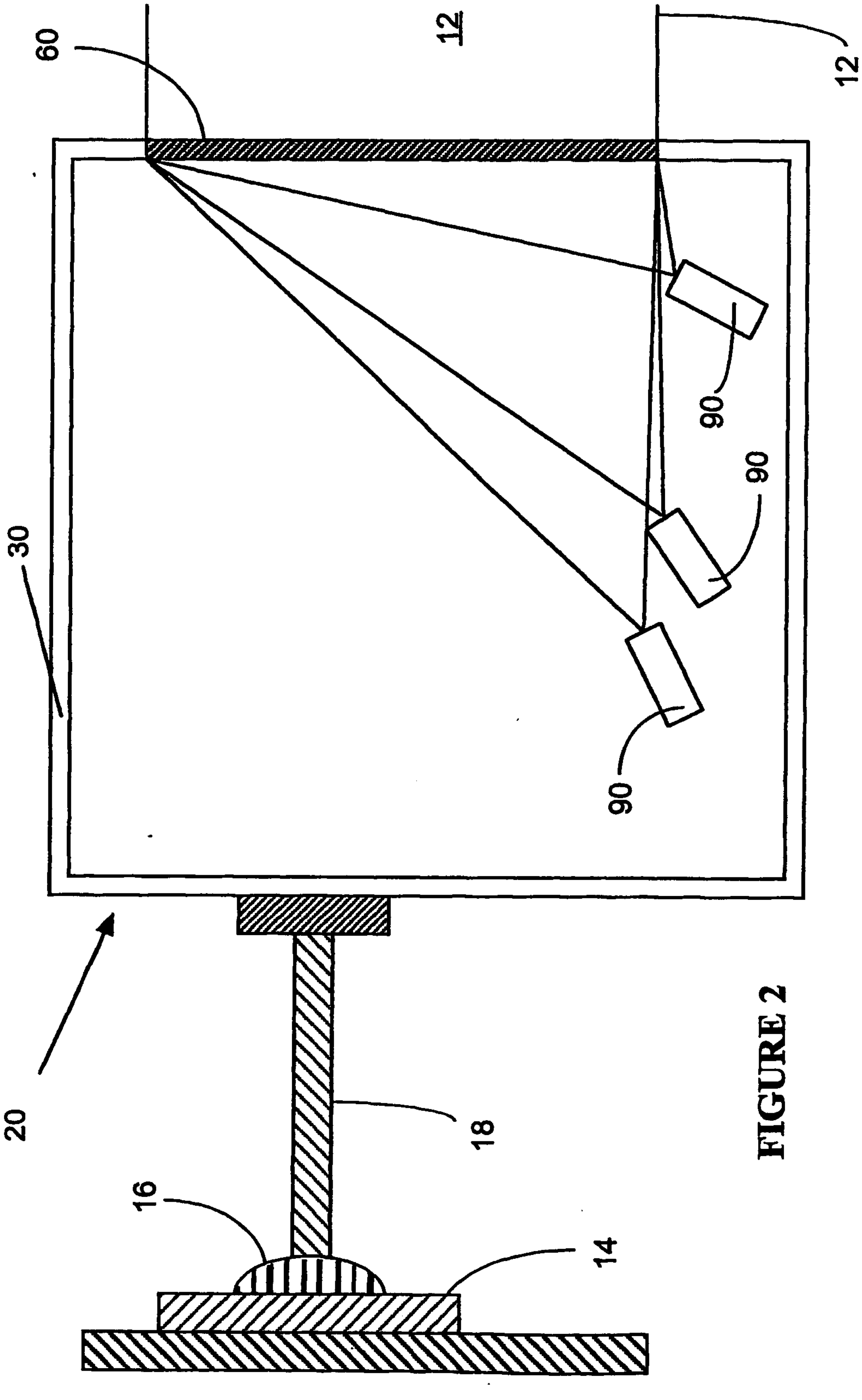


FIGURE 2

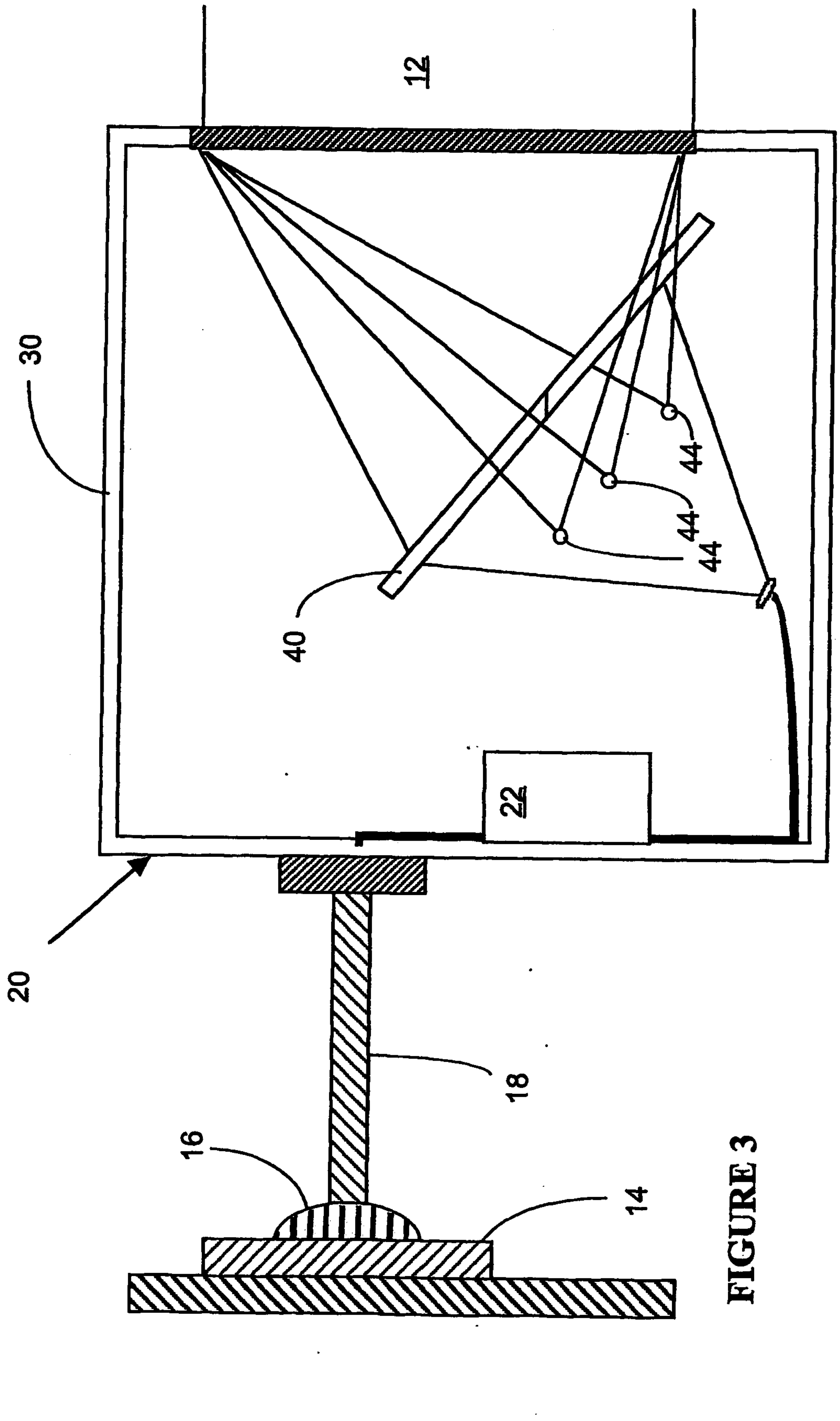


FIGURE 3

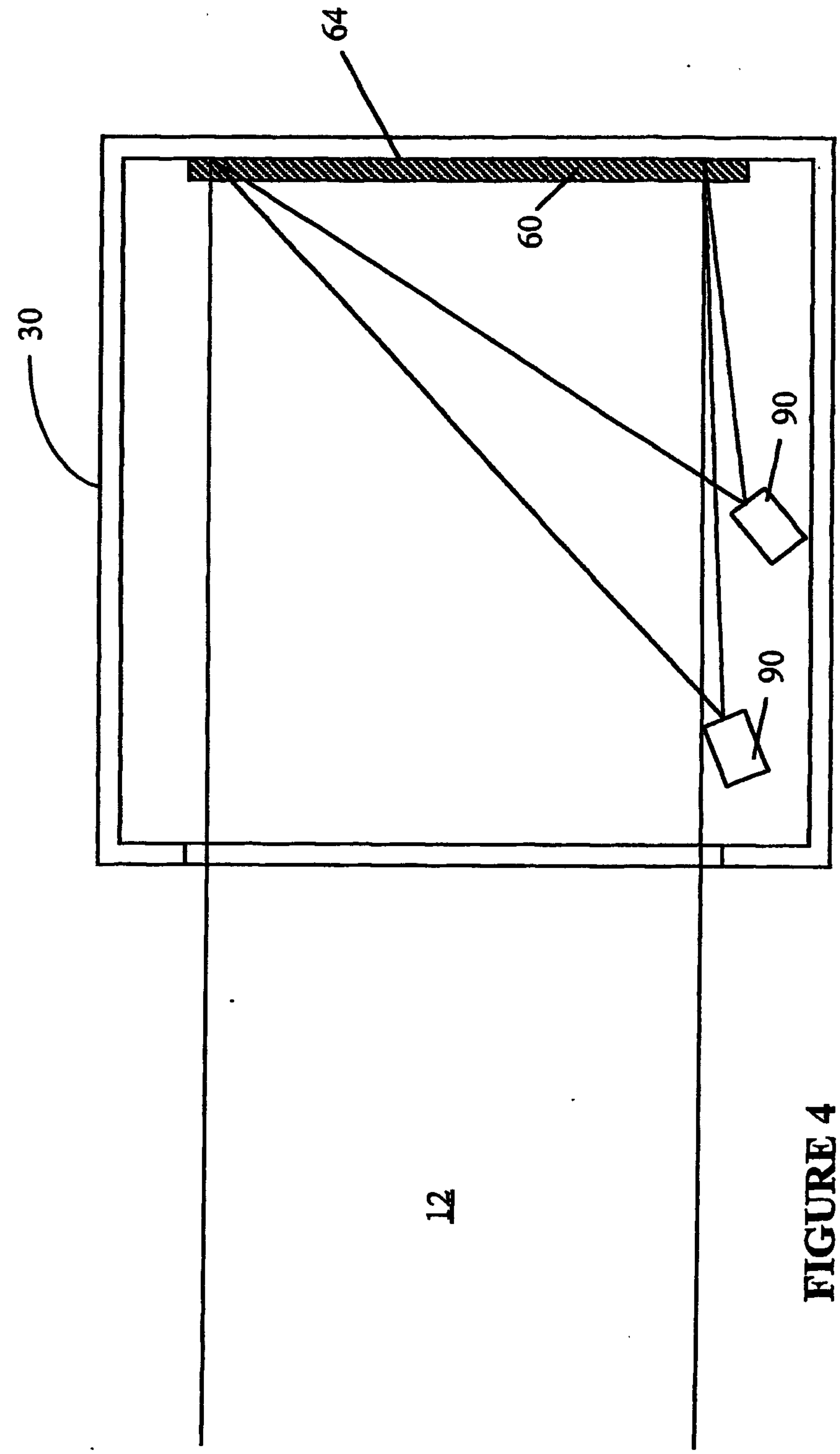


FIGURE 4

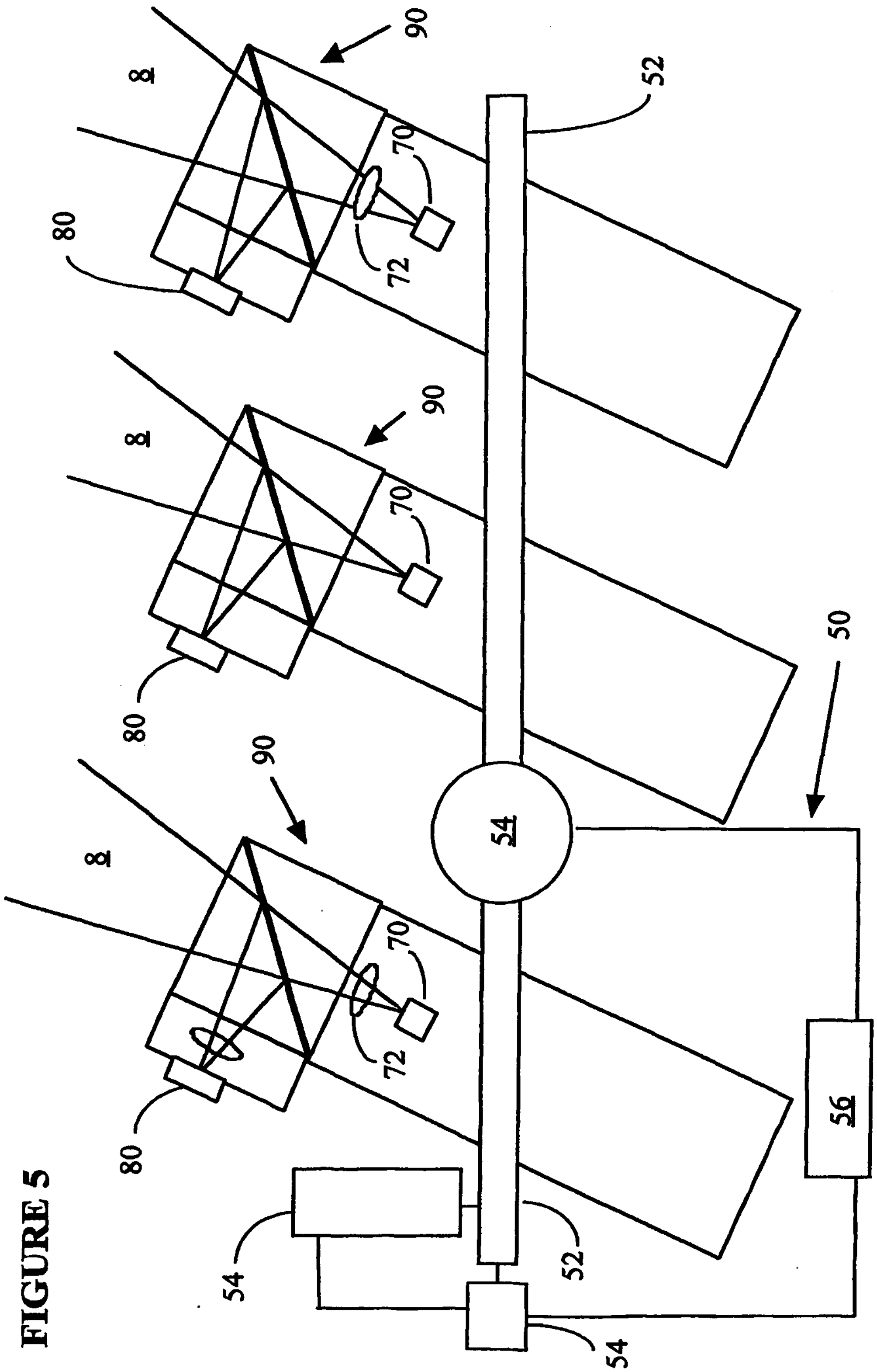


FIGURE 5

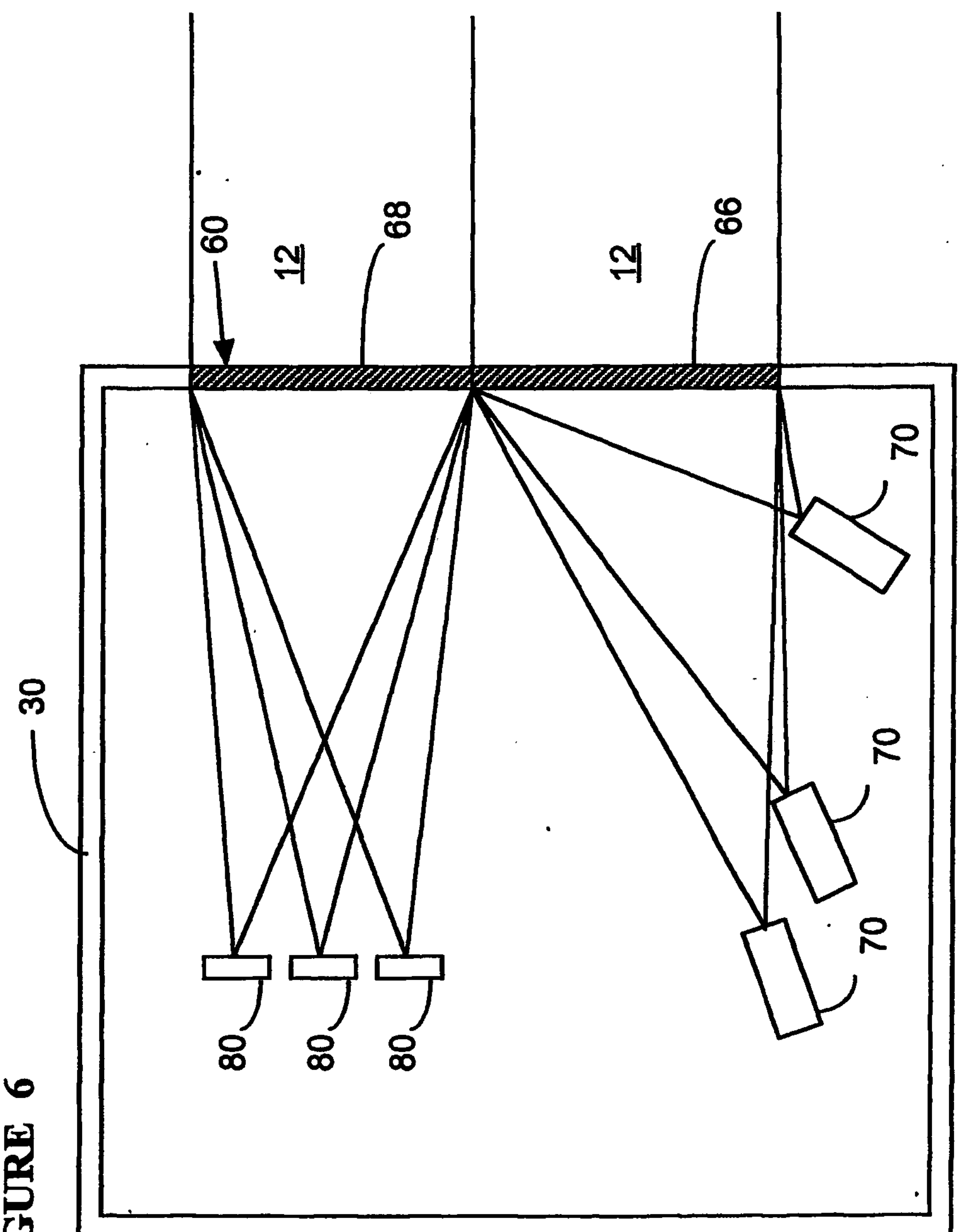


FIGURE 6

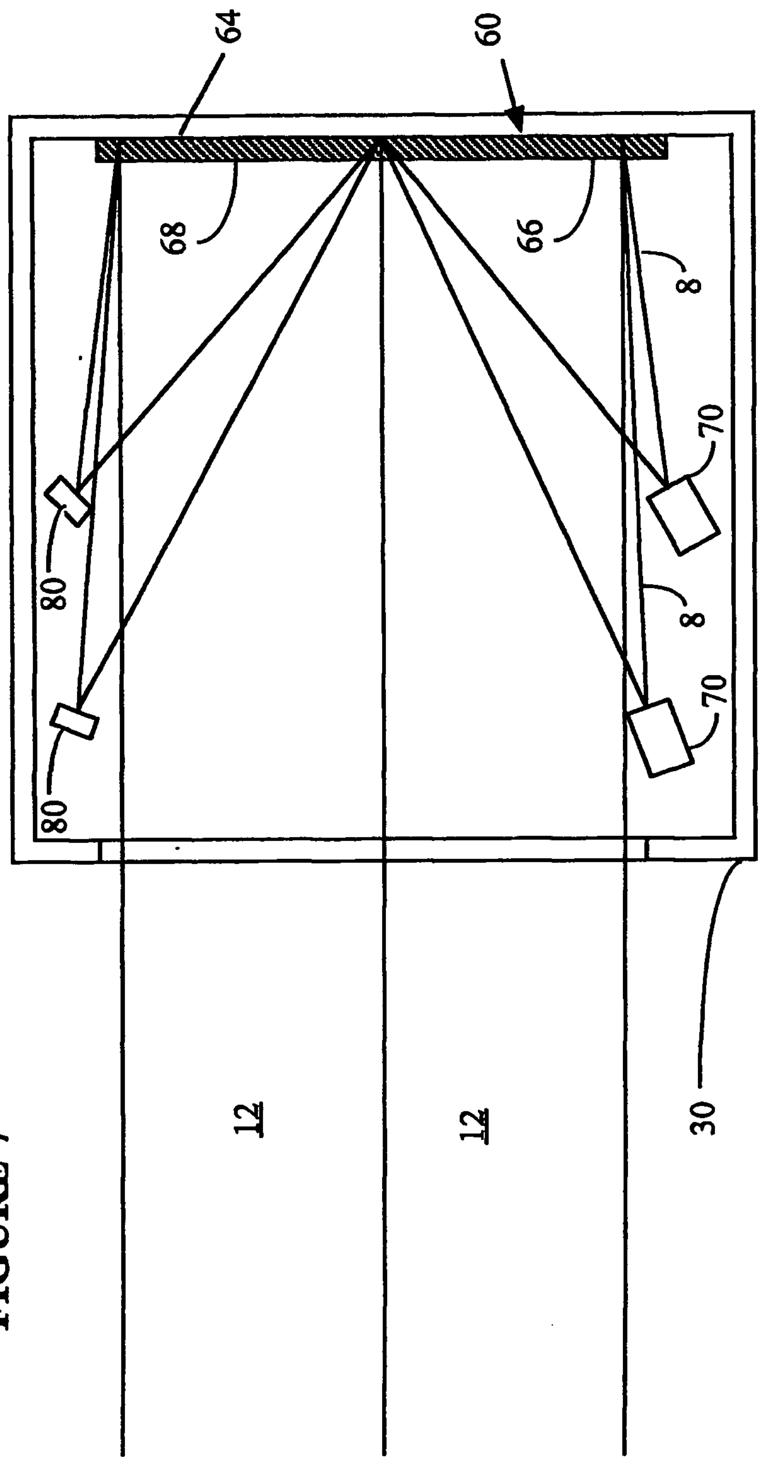


FIGURE 7